EXHIBIT 1

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CURRICULUM VITAE

Elliott Schlam, Ph.D.

Elliott Schlam is an internationally recognized authority on the electronic display industry. His consulting firm provides investment advice to the financial community and strategic, technical and marketing guidance to corporate managements as well as patent advice and expert witness services to the legal community. He has helped public and private concerns evaluate and exploit their technologies for the computer, television, HDTV, signage, industrial, military and other markets, as well as raise project related and equity investments and enter into joint development activities with strategic partners. He previously served as Vice President of Sales and Marketing for Sigmatron Nova, Inc. a flat panel display manufacturing company and as a Division Director at the U.S. Army Laboratory Command where he pioneered the technical development and use of flat panel displays in military and commercial systems. He is currently serving as a principal at New Visual Media Group, LLC.

Dr. Schlam created a major flat panel display program at the U.S. Army Laboratory Command. He conceived, managed and directed numerous in-house and contractual display programs that were coordinated to result in the incorporation of flat panel displays in a variety of military platforms. These programs ran the gamut from technology development to manufacturing methodology to technology insertion. Applications included the Abrams Tank and other vehicular, ground based and airborne installations. During this time, he also aided numerous commercial endeavors in playing a major role in the flat panel display business. Dr. Schlam has been Chairman of the Society for Information Display Manufacturing Subcommittee and he conceived, organized and is Chairman of the highly successful Society for Information Display annual Business Conference.

Dr. Schlam has made leading technical, strategic, manufacturing and business related contributions in electroluminescence, LED, active matrix, liquid crystal, plasma, field emission, CRT, HMD and other display technologies including those that are reflective and polymer based. He has lectured extensively on display technology in the U.S. and abroad and has organized and taught display courses at George Washington University, University of Wisconsin, Columbia University, University of Rhode Island and UCLA, amongst others. He has been cited in *Fortune, Barrons, Electronics, High Technology, Laser Focus, Electronic Design, Electronic News, Electrical Engineering Times* and many other journals.

Dr. Schlam earned the Ph.D., M.E.E., and B.E.E. from New York University where he was elected to Eta Kappa Nu, Tau Beta Pi and Sigma Xi and earned the M.S. in Management Science from Fairleigh Dickinson University. He is a Fellow of the Society for Information Display and has been elected to "Who's Who in the East", "Who's Who in Technology Today", "American Men and Women of Science", "Who's Who in Optical Science and Technology", "America's Registry of Outstanding Professionals", "Who's Who in Executives and Professionals" and "United Who's Who". Dr. Schlam has five issued patents.

His list of clients has included Corning Glass, Dupont, GTE, General Motors, Hewlett Packard, Intel, Litton Industries, Mitre, Microelectronics and Computer Technology Corporation, Polaroid, Texas Instruments, United Technologies, Westinghouse, and others. Dr. Schlam has also provided guidance to the United States Flat Panel Display Initiative.

Elliott Schlam's List of Publications

1: **Advances in display technolgy VI**
Schlam, Elliott
Bellingham, Wash., : SPIE—the International Society for Optical Engineering, 1986

2: **High-resolution displays and projection systems: 11-12 Febuary 1992, San Jose, California**
Schlam, Elliott
Bellingham, Wash. : SPIE, 1992

3: **Advances in display technology V : January 24-25, 1985, Los Angeles, California**
Schlam, Elliott
Bellingham, Wash., USA : SPIE—the Iternational Society for Optical Engineering, 1983

4: **Advances in display technology III : January 18-19, 1984, Los Angeles, California**
Schlam, Elliott
Bellingham, Wash. : SPIE—the International Society for Optical Engineering, 1983

5: **Advances in display technology IV : January 24-25, 1984, Los Angeles, California**
Schlam, Elliott
Bellingham, Wash. : SPIE—the International Society for Optical Engineering, 1983

6: **Higg-resolution displays and projection systems 11-12 February 1992, San Jose, California**
Schlam, Elliott.; Slusarczuk, Marko Mykola Gregory
Bellingham, Wash. : SPIE, 1992

7: **Selected papers from the 1981 SID Intenational Symposium.**
Schlam, Elliott
New York : Palisades Institute, 1982

8: **Advances in display technology V : January 24-25, 1985 Los Angeles, California**
Schlam, Elliott
Bellingham, Wash., USA : SPIE—the International Society for Optical Engineering, 1987, 1985

9: **ZnS: Er, Cu phosphor study.**
Schlam, Elliott
Springfield, Va., National Tech. Infor. Service, 1971

10: **Introduction of RGB Color into Thin Film Electroluminescent Displays by Ion Implantation .**
Ward D. Halverson, Themis Parodos, H. Paul Maruska, Richard T. Tuenge, Russell A. Budzilek and Schlam, Elliott (1994)

Elliott Schlam's List of Prior Testimony

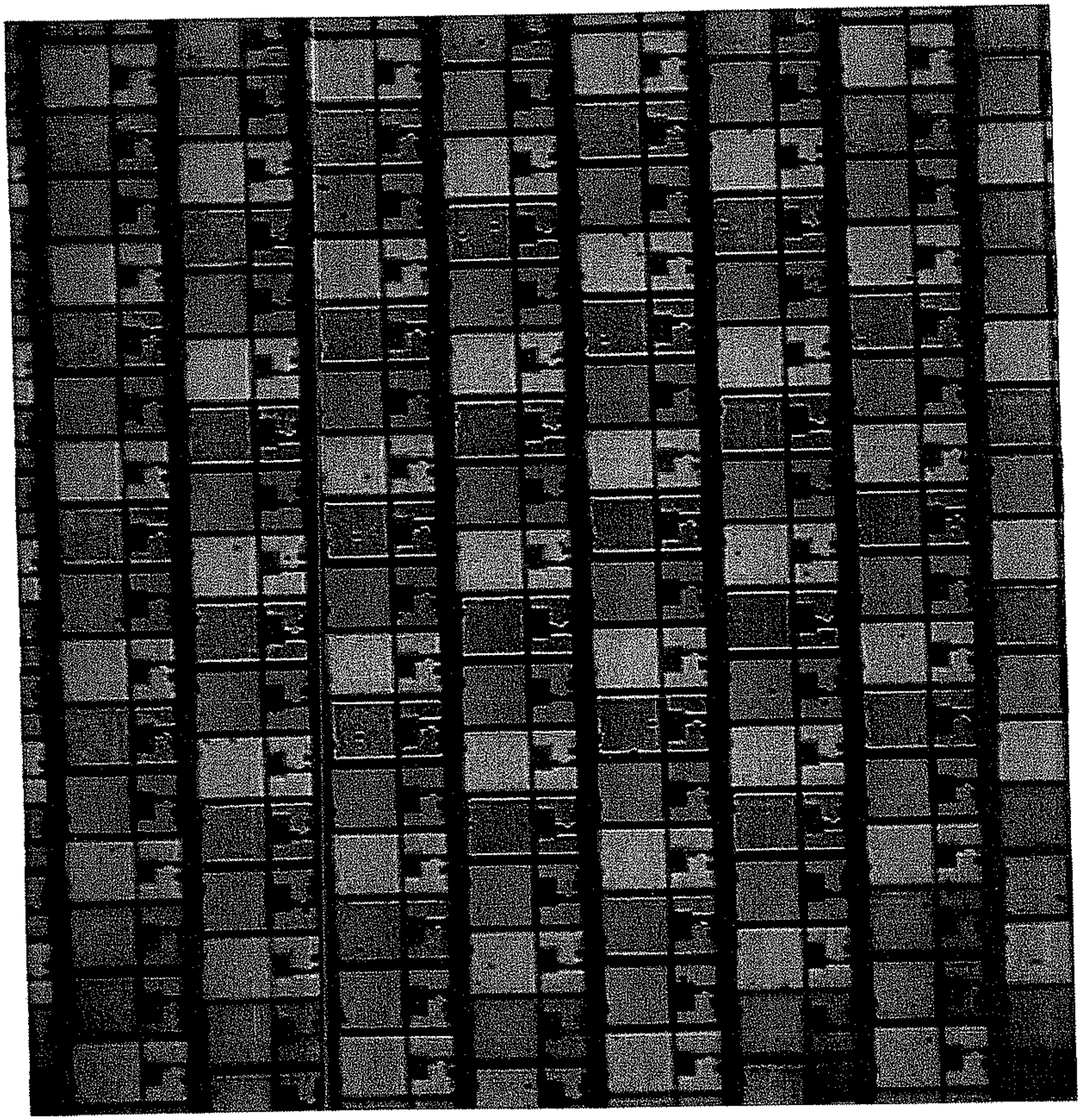
1. Certain High-Information Content Flat Panel Displays And Display Glass Therefor From Japan, Determination of the Commission Investigation No. 731-TA-469 (Final) 1991 ITC Lexis

2. Ford v. Panasonic Corporation of North America, 2007 WL 774102 (D.N.J.) 2007.

3. LG Philips LCD Co. Ltd. v. Tatung Company et al., United States District Court for the District of Delaware Case No. 1:05-cv-00292-JJF

4. Khyber Technologies Corporation v. Casio, Inc., 2004 WL 1790173 (D.Mass.) 2004.

EXHIBIT 2



E500 LCD Array

EXHIBIT 3

IBM Technical Disclosure Bulletin Vol. 33 No. 1B June 1990

[redacted] 359/69

POLARIZED BACKLIGHT FOR LIQUID CRYSTAL DISPLAY

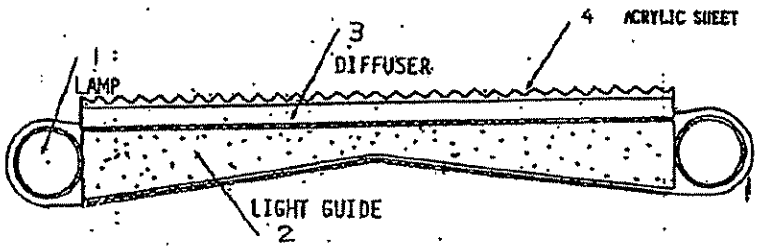


Fig. 1

Disclosed is a backlight device for a transmissive liquid crystal display. This device emits a polarized light whose polarizing axis is parallel with that of a polarizer located on one side of a liquid crystal cell and near the backlight so that the light can pass through the polarizer more than a non-polarized light.

Light which has no polarization from a backlight into the liquid crystal cell has uniform electromagnetic field for 360 degrees. Theoretically, 50 percent of electromagnetic field is absorbed and 50 percent is transmitted by the polarizer. In actuality, 58 percent of electromagnetic field is absorbed and 42 percent is transmitted.

With reference to Fig. 1, the backlight disclosed herein consists of fluorescent lamps 1, an acrylic transparent light guide 2, an acrylic translucent diffuser 3, and an acrylic sheet 4 which has an indented cross-section. Light emitted from the fluorescent lamps 1 is conducted through the light guide 2 by the law of total reflection and is scattered by the diffuser 3 for the purpose of uniform luminance. The acrylic sheet 4 not only optimizes the emitting direction of light by varying the indentation angle but also polarizes the light. Fig. 2 shows a rotation angle versus luminance measured with a polarizing prism. In this case, the acrylic sheet has a indentation angle of 90

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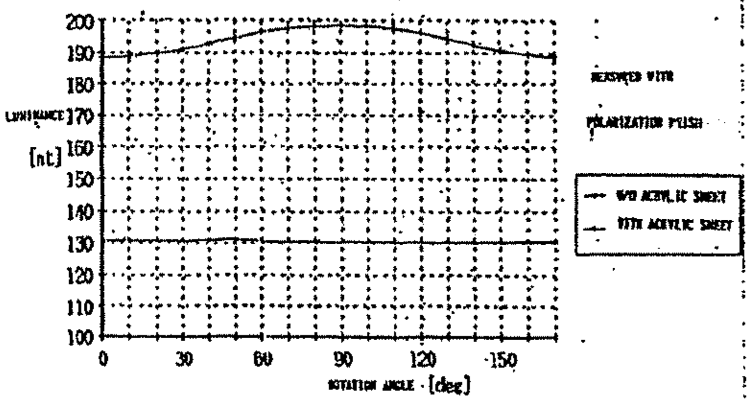

Fig. 2

degrees. This chart shows that luminance changes according to the rotation angle, that is to say, the light has polarization. Five percent of luminous increase is achieved by arranging a polarizing axis of the polarizer and transmissive axis of the acrylic sheet parallel.

In the above example, 5 percent of luminous increase is achieved in consequence of 5 percent of polarization of light. In case linear polarization of light is accomplished, the backlight device makes it possible to eliminate the polarizer located on the backlight side of the liquid crystal cell.

EXHIBIT 4

United States Patent [19]

Hathaway et al.

[11] Patent Number: 5,050,946

[45] Date of Patent: Sep. 24, 1991

[54] FACETED LIGHT PIPE

[75] Inventors: Kevin J. Hathaway, San Jose, Calif.; Richard M. Knox, Jr., Houston, Tex.; Douglas A. Arego, Spring, Tex.; Gaylon R. Kornfuerhrer, Cypress, Tex.

[73] Assignee: Compaq Computer Corporation, Houston, Tex.

[21] Appl. No.: 589,325

[22] Filed: Sep. 27, 1990

[51] Int. Cl.[5] G02B 6/00

[52] U.S. Cl. 385/33; 362/309; 362/341; 362/27; 362/32; 362/31; 385/37; 385/146; 385/901; 359/48; 359/50

[58] Field of Search 350/96.10, 96.15, 96.18, 350/96.19; 362/309, 341, 27, 31, 32

[56] References Cited

U.S. PATENT DOCUMENTS

4,257,084	3/1981	Reynolds	362/31
4,277,817	7/1981	Hehr	362/31
4,323,951	4/1982	Pasco	362/27
4,528,617	7/1985	Blackington	362/32
4,706,173	11/1987	Hamada et al.	362/341
4,799,137	1/1989	Aho	362/309
4,883,333	11/1989	Yanez	350/96.10

FOREIGN PATENT DOCUMENTS

3825436	3/1989	Fed. Rep. of Germany	350/96.10
0073206	4/1987	Japan	350/96.10
0271301	11/1988	Japan	350/96.10
0287803	11/1988	Japan	350/96.10

Primary Examiner—Georgia Epps

Attorney, Agent, or Firm—Pravel, Gambrell, Hewitt, Kimball & Krieger

[57] ABSTRACT

A light pipe used for backlighting liquid crystal displays has a planar front surface and a stairstepped or faceted back surface. Light is injected from the ends of the light pipe from cold or hot cathode, apertured, fluorescent lamps. The cold cathode lamps are preferably insulated to raise their operating temperature. The back surface has a series of planar portions parallel to the front surface connected by facets, which are angled so that the injected light reflects off the facets and through the front surface. A reflector having a planar, highly reflective, highly scattering surface or a sawtoothed or grooved upper surface is located adjacent to and parallel with the light pipe back surface to reflect light escaping from the back surface back through the light pipe to exit the front surface. The axis of grooves is preferably slightly skewed from the facet axis to reduce moire pattern development. A low scattering or loss diffuser is located adjacent to and parallel with the light pipe front surface to reduce moire pattern development. The liquid crystal display is located over the low scattering diffuser. A separate injector may be located between the lamp and the light pipe to better couple the light into the light pipe.

37 Claims, 6 Drawing Sheets

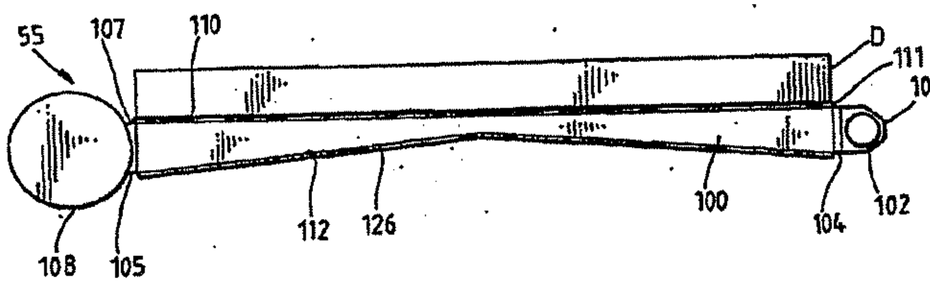

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FIG.1
(PRIOR ART)

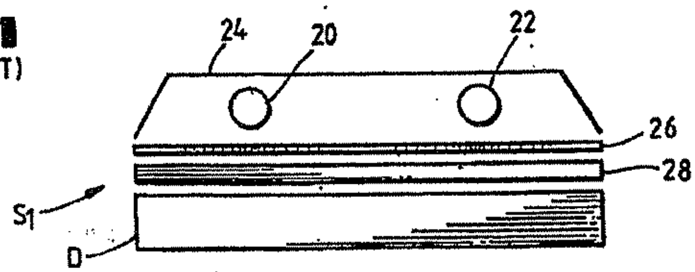


FIG.2
(PRIOR ART)

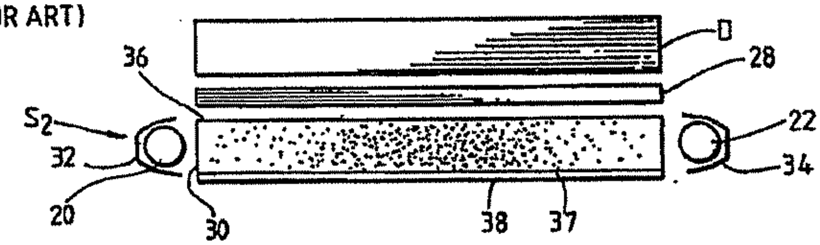


FIG.3
(PRIOR ART)

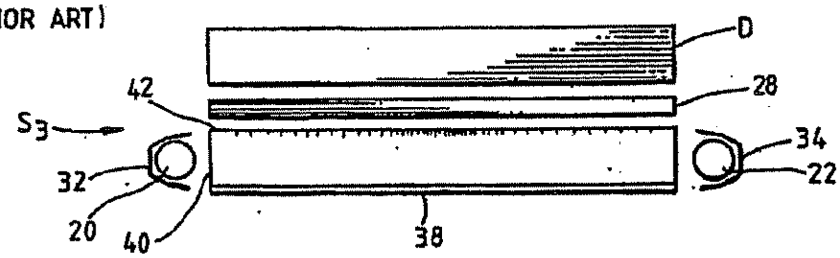


FIG.4
(PRIOR ART)

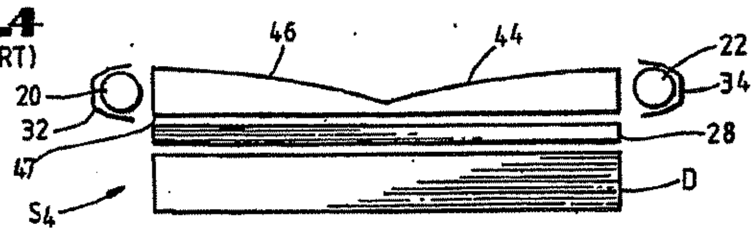


FIG.6

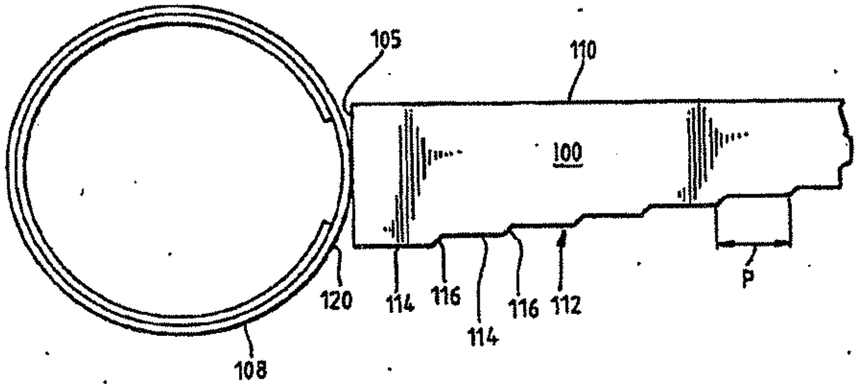
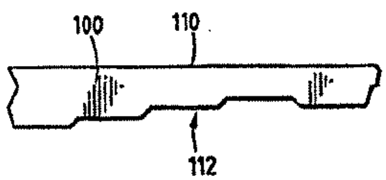


FIG.7



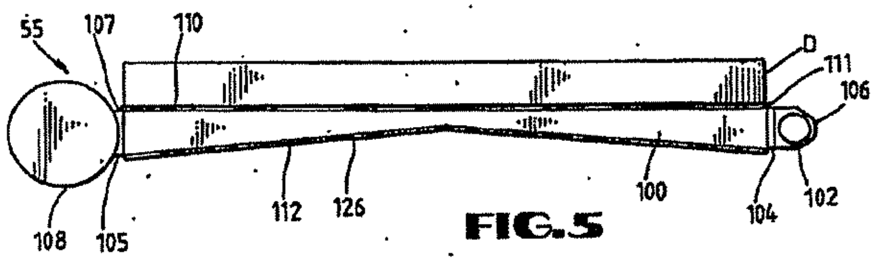


FIG.5

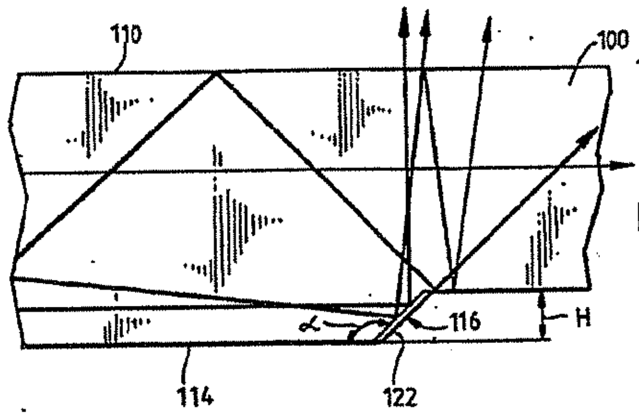
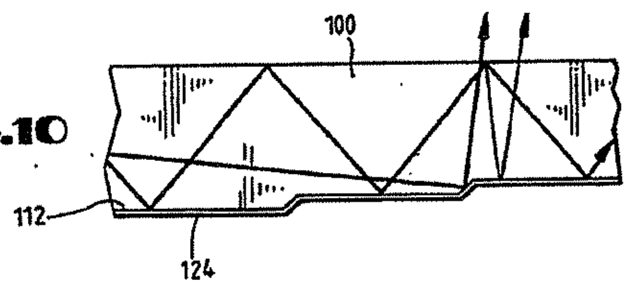


FIG.8

FIG.10



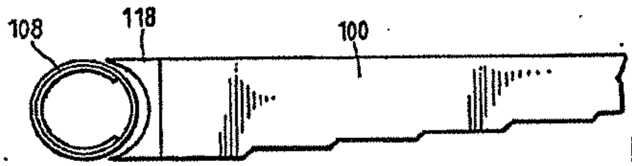


FIG.11

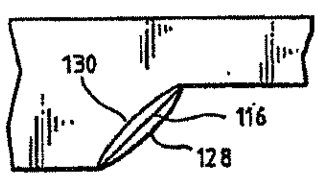
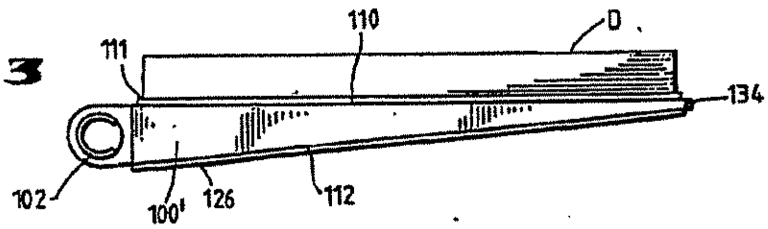


FIG.12

FIG.13



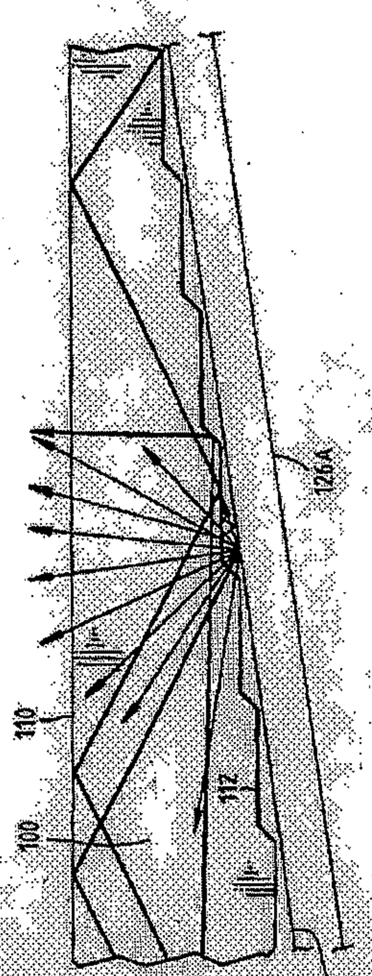


FIG.9A

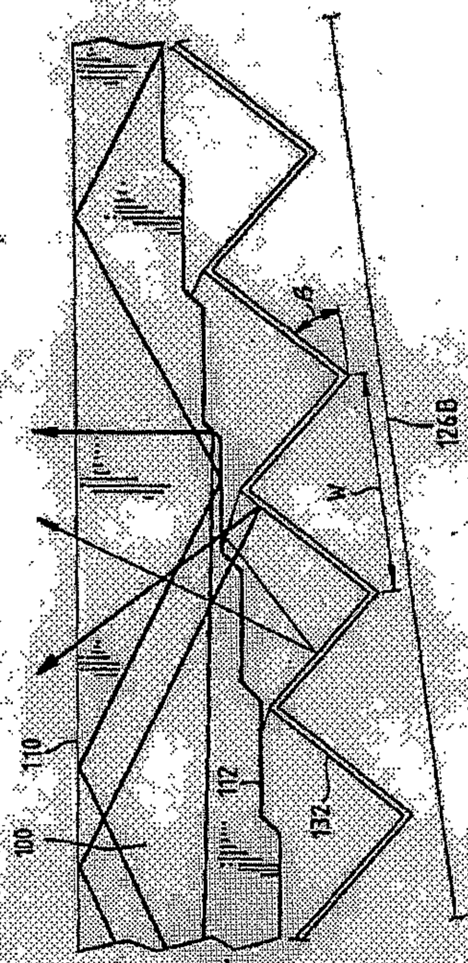


FIG.9B

FIG.14

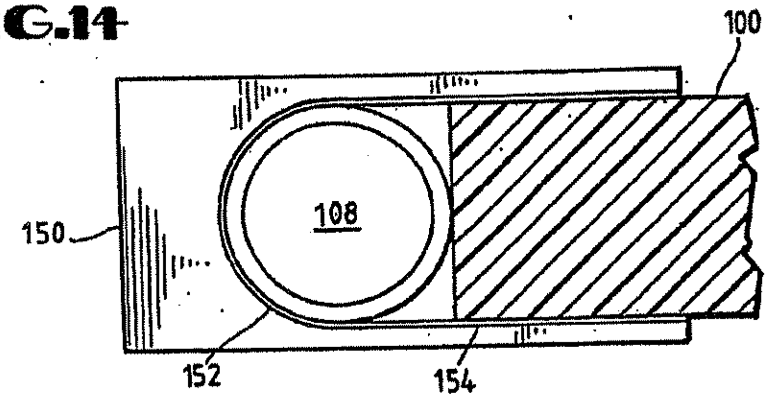


FIG.15

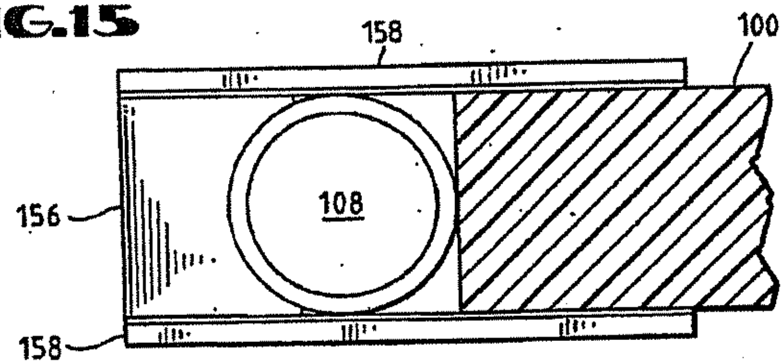
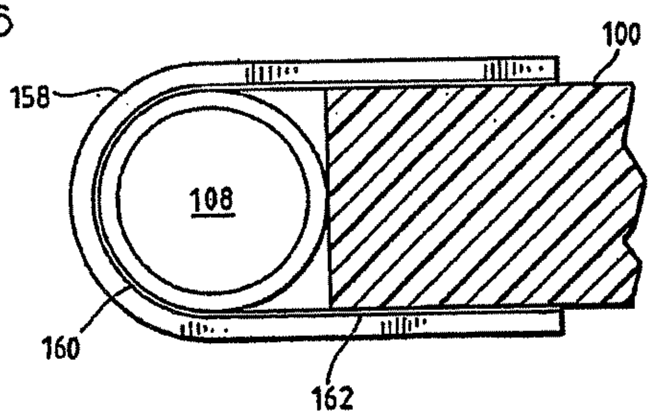


FIG.16



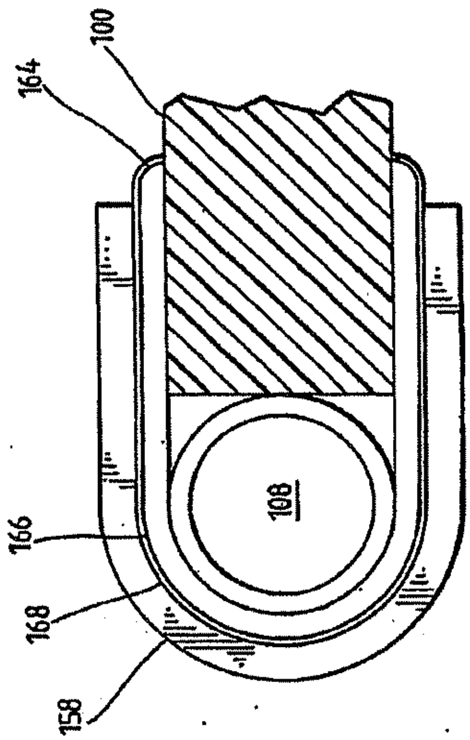


FIG.17

FACETED LIGHT PIPE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to backlighting systems used with liquid crystal displays, and more particularly to light pipe systems.

2. Description of the Related Art

Liquid crystal displays (LCD's) are commonly used in portable computer systems, televisions and other electronic devices. An LCD requires a source of light for operation because the LCD is effectively a light valve, allowing transmission of light in one state and blocking transmission of light in a second state. Backlighting the LCD has become the most popular source of light in personal computer systems because of the improved contrast ratios and brightnesses possible. Because conventional monochrome LCD's are only approximately 12% transmissive and color LCD's are only approximately 2% transmissive, relative large amounts of uniform light are necessary to provide a visible display. If power consumption and space were not of concern the necessary level and uniformity of backlight could be obtained.

However, in portable devices power consumption, which directly effects battery life, and space are major concerns. Thus there is a need to obtain a sufficiently uniform and bright backlight level with as little power as possible in as little space as possible at, of course, as low a cost as possible.

Numerous designs exist which trade off various of these goals to achieve a balanced display. Several of these designs, such as light curtains and light pipes, are shown in the figures and will be described in detail later. The designs generally trade off uniformity of backlighting for space or efficiency. The designs utilize various scattering means and a final diffuser before the light is presented to the LCD. The scattering means and the diffusers both allow loss of light and thus reduce the efficiency of the transfer from the light source to the LCD. While the designs are adequate in some cases, the demands for longer battery life with monochrome LCD's or equal battery life with color LCD's are present, as is a desire for the use of less space.

SUMMARY OF THE INVENTION

The present invention is a faceted, parallel surface light pipe design. Light sources, preferably reflector or apertured fluorescent lamps, but alternatively uniform lamps, supply light to one or both ends of a light pipe. The front surface of the light pipe, on which is positioned a low loss diffuser, which in turn is in contact with the LCD, is planar, while the back surface of the light pipe is generally parallel to the front surface, but has a stair stepped or faceted surface. The facets are preferably formed at an angle so that the light injected into the ends of the light pipe is reflected off the facets and through the front surface. The pitch or step length of the facets is such that the faceting structure is not visible to the human eye. The step height of the facets is preferably in the micron range and may increase with the distance from the lamp. A planar, white, diffuse reflector, which is highly reflective and high scattering, is positioned parallel to the back surface of the lightpipe. This allows light leaving the back surface to be reflected back through the front surface of the light pipe. Alternatively, the reflector can have a sawtoothed or grooved surface. The axis of the sawtooth ridges is preferably slightly askew the axis of the facets to reduce the effects of moire pattern development. The reflections can be satisfactorily controlled so that little light is returned to the light source, little light leaves the other end of the light pipe and little light is trapped in the light pipe.

This design is in contrast to the low efficiency of the various scattering techniques of the prior art which allow the losses described. The pitch and step height are sufficient so that a conventional diffuser is not required before the LCD, thus allowing further relative increased light transmission and efficiency. However, a low loss diffuser is preferably located between the light pipe and the display to overcome moire pattern development. Various designs of the end of the light pipe and the actual facet profile and pitch can be used to alter specific aspects of the transmission to vary the light output.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the prior art and the present invention can be obtained when the following detailed description of the preferred embodiment is considered in conjunction with the following drawings, in which:

FIGS. 1-4 are views of various backlighting systems of the prior art;

FIG. 5 is a view of a backlighting system according to the present invention including a light pipe and light sources;

FIGS. 6 and 7 are greatly enlarged views of portions of the backlighting system of FIG. 5;

FIGS. 8, 9A, 9B and 10 are greatly enlarged views of portions of the light pipe of FIG. 5 showing light action;

FIG. 11 is a greatly enlarged view of an alternate injector according to the present invention;

FIG. 12 is a greatly enlarged, view of a facet of the light pipe of FIG. 5;

FIG. 13 is an alternate single source backlighting system according to the present invention; and

FIGS. 14 to 17 are alternative designs for a lamp reflector according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to discussing the present invention, it is considered appropriate to further discuss various designs in the prior art to explain the present technology and thus make clear the scope of the present invention.

FIG. 1 generally discloses a conventional light curtain system used in providing backlight to an LCD. Two uniform output cold cathode florescent lamps 20 and 22 are the basic light source for the system S1. A reflector 24 generally having a white reflective surface facing the lamps 20 and 22 is used to redirect the light being emitted by the lamps 20 and 22 in directions other than towards the LCD D. A light blocking layer 26 is used to reduce any hot, nonuniform spots which would occur directly over the lamps 20 and 22 to provide a first level of uniformity to the light. The blocking layer 26 is preferably formed of a variable opacity mylar material, with the material being very opaque near the lamps 20 and 22 and becoming more translucent or transparent away from the lamps. This variable opacity is generally provided by a printed pattern on the surface

of the blocking layer 26. However, because the light is not sufficiently uniform after passing through the blocking layer 26, a diffuser 28, which is generally a translucent plastic material, is used to further diffuse the light and produce a more uniform display. However, the diffuser generally reduces the light transmission by approximately 10% to 50%, which greatly reduces the efficiency of the overall backlighting system S1. The light curtain system S1 is relatively thick and as the lamps are placed closer to the blocking layer alignment problems increase, reducing the capability to economically manufacture the system S1.

Two variations of similar light pipe systems are shown in FIGS. 2 and 3 and are generally referred to as systems S2 and S3. Both systems again generally use uniform emission lamps 20 and 22, but the lamps are located at the ends of a light pipe 30. White reflectors 32 and 34 are provided around the lamps 20 and 22 so that the uniform light is directed into the light pipe 30. The light pipe 30 includes a variable density scattering structure so that the light is projected out the front surface 36 of the light pipe 30, through the diffuser 28 and through the LCD D. In the backlighting system S2 the light pipe 30 uses titanium oxide particles or other particles located in the light pipe 30 to perform the scattering function. Preferably the density of the particles is greater near the center of the display and lesser near the ends of the display near the lamps 20 and 22 to produce a uniform light because of the effective light density, which reduces approaching the center of the light pipe 30. A mirrored or fully reflective surface 38 is applied to the back surface 37 of the light pipe 30 so that any light which is scattered in that direction is reflected in an attempt to have the light transmitted through the front surface 36 of the light pipe 30. However, this light might again be scattered and so various losses can occur. The backlighting system S3 uses a scattering structure printed on the front surface 42 of the light pipe 40 to provide the scattering effect. In both systems S2 and S3 a diffuser 28 is required to provide a sufficiently uniform light source to the LCD D. In these designs light can become trapped in the light pipe 40 and can readily be transmitted from one end to the other and thus be lost, reducing overall efficiency.

An alternate prior art light pipe design is shown in FIG. 4, and is generally referred to by S4. In this case a double quadratic wedge light pipe 44 is used in contrast to the parallel light pipes 30 and 40 of the systems S2 and S3. The back surface 46 of the light pipe 44 is a relatively constant, diffuse surface, with the front surface 47 being a clear or specular surface. The curve formed by the back surface 46 is a quadratic curve such that more light which impinges on the back surfaces is reflected through the front surface as the light approaches the center of the light pipe 44. In this way a relatively uniform light source can be developed, but a diffuser 28 is still required to provide an adequately uniform source. This design has problems in that some light does leak out at low angles out the back and in some cases light is sent back to the source. Additionally, there are some problems at the exact center of the display.

Thus while the light pipe designs S2, S3 and S4 are generally thinner designs than the light curtain system S1, they have problems related to having to turn the light generally ninety degrees and thus have a lower efficiency than the light curtain design, which in turn has the drawback it is a relatively thick design which

limits the design possibilities in portable computer systems and television applications.

A backlight system according to the present invention, generally referred to as S5, is shown in FIG. 5. A faceted, dual source light pipe 100 is coupled to an LCD D. FIG. 5 shows two alternate lamp variations. In one variation a uniform dispersion lamp 102 may be located adjacent to an optional separate injector 104. The lamp 102 is preferably surrounded by a reflector 106. The separate injector 104 is used to couple the transmitted light from the lamp 102 into the light pipe 100. The second and preferred embodiment of the light source is a lamp 108 which is a cold cathode, reflector florescent lamp having an aperture located adjacent to the end 105 of the light pipe 100. A reflector 106 may be used with the lamp 108. For use with monochrome displays D a cold cathode lamp is preferred to keep power consumption at a minimum, the backlight S5 being sufficiently efficient that the added light output is not considered necessary. However, if a color display D is used, a hot cathode lamp is preferred because of the need for maximum light output. Additionally, a reflector lamp is preferred to an aperture lamp for lamps of the diameter preferably being used in the preferred embodiment. A reflector lamp has a first internal coating of the reflective material, which then has an aperture developed and is finally completely internally coated with phosphor. The aperture lamp is first coated internally with the reflective material, then with the phosphor and finally the aperture is developed. Given the relatively large arc of the aperture, the additional phosphor present in the reflector lamp more than offsets the lower brightness because the light must travel through the phosphor coating the aperture. An index matching material 107 may optionally be provided between the lamp 108 and the light pipe 100.

As shown the upper surface of the light pipe 100 is planar, specular and is adjacent a low trapping and low scattering diffuser 111. The diffuser 111 preferably produces less than 10% brightness drop and is used to reduce the effects of any moire pattern developed between the light pipe 100 and the LCD display D because of the pitch and alignment variations between the items. The LCD display D is located over the diffuser 111. A back surface reflector 126 is located parallel to the back surface 112 of the light pipe 100 to reflect light through the back surface 112 back through the light pipe 100 and out the front surface 110. In the macroscopic view of FIG. 5 the back surface 112 of the light pipe 100 appears to be a straight wedge or planar surface but in the enlarged views shown in FIGS. 6 and 7 the stair stepped or faceted structure is clearly shown.

The back surface 112 consists of a series of portions 114 parallel with the front surface 110, with a series of facets 116 leading to the next parallel portion 114. FIG. 6 is the enlarged view showing the coupling of the apertured lamp 108 with the light pipe 100, while FIG. 7 shows the central portion of a dual source light pipe 100. Preferably the lamp 108 is a fluorescent type lamp with an aperture height approximating the thickness of the light pipe 100. The light pipe 100 preferably has a thickness of 5 mm or less at the outer edges and a thickness of 1 mm in the center. The thickness of 1 mm is preferred because the light pipe 100 is preferably made of polymethyl methacrylate (PMMA) and so this minimum thickness is provided for mechanical strength reasons. Other materials which can develop and maintain the faceted structure may be used to form the light

pipe 100. The light pipe 100 is restrained to a thickness of approximately 5 mm so that when combined with the LCD D, the reflector 126 and the diffuser 111 of the preferred embodiment, the overall unit has a thickness of less than ½ of an inch, not counting the lamp 108, thus saving a great deal of space as compared to prior art light curtain designs. The lamp 108 can have a diameter greater than the thickness of the light pipe 100, allowing a narrower aperture, as shown in FIGS. 5 and 6, or preferably can have a diameter approximately equal to the thickness of the light pipe 100 as shown in FIGS. 5 and 11, with an angularly larger aperture.

If the preferred cold cathode lamp is used as the lamp 108, the lamp 108 may run at temperatures below the optimum efficiency temperature because of the small size of the lamp 108. Therefore it is preferable to use a reflector 106 which is also insulating. Four alternate embodiments are shown in FIGS. 14–17. In the embodiment of FIG. 14, a U-shaped insulator 150 is used. Inside the insulator 150 and before the light pipe 100 can be a white reflective material 152. This material 152 can be adhesively applied if needed, but preferably the insulator 150 is formed of a white, reflective material. The presently preferred material is a high density polystyrene foam, but silicone, polyethylene, polypropylene, vinyl, neoprene or other similar materials can be used. A double sided adhesive layer 154 is used to retain the insulator 150 to the light pipe 100. The insulator 150 traps the heat produced by the lamp 108, thus raising the lamp operating temperature and, as a result, its efficiency. It is desireable that the insulator 150 and associated materials be able to withstand 100° C. for extended periods and have a moderate fire resistance.

In the variation of FIG. 15, an expanded polystyrene block 156, or similar material, is combined with two strips of foam tape 158 to form the insulating reflector 106. Preferably the adhesive surface of the tape 158 includes a mylar backing for strength. In the variation of FIG. 16 foam tape 158 is again used, but this time longitudinally with the lamp 108 to form a U-shape. Preferably the inside of the U is covered by a reflective tape 160, while the foam tape 158 is fixed to the light pipe 100 by a double sided metallized mylar tape 162.

Yet another variation is shown in FIG. 17. A clear acrylic material 164 surrounds the lamp 108 and is attached to the light pipe 100 by a suitable adhesive layer. The outer surface 166 of the acrylic material 164 is coated with metallizing material 168 so that the outer surface 166 is a reflector. In this manner light which is emitted from the lamp 108 at locations other than the aperture is reflected through the acrylic material 164 into the light pipe 100, instead of through the lamp 108 as in FIGS. 14 to 16. While the acrylic material 164 will provide some insulation, it may not be sufficient to raise the lamp 108 temperature as desired and so foam insulating tape 158 may be used over the acrylic material 164 for better insulation. In this case the entire inner surface of the foam tape 158 may be adhesive coated as the reflective layer is present on the acrylic material 164.

A separate injector 104 may be used to couple the light being emitted by the lamp 108 into the light pipe 100, but preferably the end 105 of the light pipe 100 is considered the injector. The injector 104 or end 105 is preferably a flat surface which is polished and specular, that is non-diffuse, and may be coated with anti-reflective coatings. A flat, specular surface is preferred with a light pipe material having an index of refraction greater than 1.2, which results in total internal reflection of any injected light, which the facet structure will project out the front surface 110.

Several other alternatives are available for the injector, such as index matching material 107 to match the lamp 108 to the light pipe 100 to eliminate surface reflections. The index matching material 107 is a clear material, such as silicone oil, epoxy or polymeric material, which contacts both the lamp 108 and the end 105. Alternatively, the injector 118 can be shaped to conform to the lamp 108 with a small air gap (FIG. 11). This curved surface of the injector 118 helps locate the lamp 108. Additionally, a cylindrical fresnel lens can be formed on the end 105 or separate injector 104 to help focus the light being emitted from the lamp 108. Its noted that a cylindrical fresnel lens is preferred over a true cylindrical lens to limit leakage of the light. Alternate lenses can be developed on the separate injector 104 or end 105 which in combination with the facets 116 can effect the output cone of the light as it exits the light pipe 100. Preferably the output cone is the same as the viewing angle of the LCD D so that effectively no light is being lost which is not needed when viewing the LCD D, thus increasing effective efficiency of the system.

FIG. 8 shows a greatly enlarged view of a portion of one facet 116 and several parallel portions 114 of the light pipe 100. As can be seen the parallel back surface portions 114 are parallel with the front surface 110, both of which are specular, so that the light pipe 100 preferably utilizes only specular reflections and does not utilize diffuse reflection or refraction, except in minor amounts. By having primarily only specular reflections it is possible to better control the light so that it does not leave the light pipe 100 in undesired directions, thus allowing better focusing and less diffusion. Thus the basic propagation media of the light pipe 100 is that of a parallel plate light pipe and not of a wedge or quadratic. The facet 116 preferably has an angle α of 135 degrees from the parallel portion 114. This is the preferred angle because then light parallel to the faces 110 and 114 is transmitted perpendicular to the light pipe 100 when exiting the front face 110. However, the angle can be in any range from 90 to 180 degrees depending upon the particular output characteristics desired. The pitch P (FIG. 6) or distance between successive facets 116 is related to and generally must be less than the visual threshold of the eye which, while proportional to the distance the eye is from the LCD D, has preferred values of 200 to 250 lines per inch or greater. In one embodiment without the diffuser 111 the pitch P is varied from 200 lines per inch at the ends of the light pipe 100 near the lamps 108 to 1000 lines per inch at the center so that more reflections toward the front face 110 occur at the middle of the light pipe 100 where the light intensity has reduced. The pitch in the center is limited to 1,000 lines per inch to provide capability to practically manufacture the light pipe 100 in large quantities, given the limitations of compression or injection molding PMMA. If the diffuser 111 is utilized, the pitch can go lower than 200 lines per inch because of the scattering effects of the diffuser 111. The limit is dependent on the particular diffuser 111 utilized. Thus the use of the diffuser 111 can be considered as changing the limit of visual threshold. In one embodiment of the present invention the facet height H (FIG. 8) ranges from approximately 1 micron near the end 105 to 10 microns near the middle, the farthest point from a lamp. In the drawings the facet height is greatly enlarged relative to

the pitch for illustrative purposes. The preferred minimum facet height is 1 micron to allow the light pipe 100 to be developed using conventional manufacturing processes, while the preferred maximum facet height is 100 microns to keep overall thickness of the light pipe 100 reduced. It is noted that increasing the facet height of a facet 116 at any given point will increase the amount of light presented at that point, referred to as the extraction efficiency, so that by changing the pitch P, facet height H and facet angle α varying profiles and variations in uniformity of the light output from the front surface 110 can be developed as needed.

While the desire is to use purely specular reflective effects in the light pipe 100, some light will be split into transmitted and reflected components. Even though there is total internal reflection of light injected into the light pipe 100 by the front surface 110 and parallel portions 114, when the light strikes a facet 116 much of the light will exceed the critical angle and develop transmitted and reflected components. If the light is reflected from the facet 116, it will preferentially be transmitted through the front surface 110 to the viewer. However, the transmitted component will pass through the back surface 112. Thus a reflective coating 122 may be applied to the facet 116. This reflective material 122 then redirects any light transmitted through the facet 116. This is where the greatest amount of transmission is likely to occur because of the relatively parallel effects as proceeding inward on the light pipe 100.

A design trade off can be made here based on the amount of light exceeding the critical angle being reflected back from the front surface 110, through the back surface 112 or through the facets 116. If there is a greater amount of this light which will be transmitted out the back surface 112 and lost, it may be desirable to fully coat the back surface 112 as shown in FIG. 10 so that the entire back surface 112 is coated by a reflector material 124. Because the reflector material is preferably aluminum or other metals the efficiency of the reflector 124 is not 100% but typically in the range of 80% to 90%, some reflective loss occurs at each point. Thus there is some drop in efficiency at each time the light impinges on the reflector 124, but based on the amount of high angle light present, more light may actually be transmitted through the front surface 110, even with the reflective losses. If the lamp transmits much more parallel light, then the coating of the parallel portions 114 with reflective material may not be necessary.

In the embodiments shown in FIGS. 9A and 9B no reflective coatings are actually applied to the light pipe 100 but instead a reflector plate 126A or 126B is located adjacent the back surface 112 of the light pipe 100. In the preferred embodiment shown in FIG. 9A, the reflector plate 126A is planar and has a white and diffuse surface 170 facing the back surface 112 of the light pipe 100. The surface 170 is highly reflective and high scattering to reflect the light passing through the back surface 112 back through the light pipe 100 and out the front surface 110. The thickness of the reflector plate 126A is as needed for mechanical strength.

In an alternate embodiment shown in FIG. 9B, the front or light pipe facing surface 132 of the reflector plate 126B has a sawtoothed or grooved surface, with the blaze angle β of the sawtooth being in the range of 30 to 60 degrees, with the preferred angle being approximately 40 degrees. The pitch W of the sawteeth is different from the pitch P of the light pipe facets to to reduce the effects of moire pattern development between the light pipe 100 and the reflector 126B. The pitches are uniform in the preferred embodiment and are in the range of 1–10 mils for the facets and 1–10 mils for the reflector grooves, with the preferred facet pitch P being 6 mils and the sawtooth pitch W being 4 mils. The sawtooth pitch W can be varied if the facet pitch P varies, but a constant pitch is considered preferable from a manufacturing viewpoint. The thickness of the reflector plate 126B is as needed for mechanical support.

Additionally, the longitudinal axis of the sawteeth is slightly rotated from the longitudinal axis of the facets to further reduce the effects of moire pattern development. The sawtooth surface 132 is coated with a reflecting material so that any impinging light is reflected back through the light pipe 100 as shown by the ray tracings of FIG. 9. Further, the sawteeth can have several different angles between the preferred limits to better shape the light exiting the light pipe 100.

The majority of the light which impinges on the sawtooth surface 132 or the diffuse surface 170 will proceed directly through the light pipe 100 and emerge from the front face 110 because the light pipe 100 is effectively a parallel plate because the facet area is only a very small percentage as compared to the flat portion of the back surface 112. Thus the light which exits the back surface 112 of the light pipe 100 is reflected back through the light pipe 100 to exit the front surface 110 and contribute to the emitted light with little loss.

Additionally, the actual facet profile 116 is not necessarily planar. As shown in FIG. 12, the actual facet profile may be slightly concave 128 or slightly convex 130. The facets 116 then form a lenticular array and can be curved as desired to help tailor the output profile of the light cone. Additionally, the facet 116 surface may be roughened to increase scattering if desired.

While the design of the light pipe 100 illustrated in FIG. 5 use lamps at both ends in a dual light source arrangement, light could be provided from only one end in a single source configuration as shown in FIG. 13. The end opposite the light source 102 is then the thinnest portion of the light pipe 100' and a reflective surface 134 is provided to limit losses from the end of the light pipe 100'. The light pipe 100' still has the planar front surface 110, a faceted back surface 112, a reflector plate 126 and a low loss diffuser 111 and the other variations described above are applicable. The facet pitch and height are preferably varied as previously described to develop greater light redirection to help compensate for the lesser total amount of light supplied by the light source 102.

Having described the invention above, various modifications of the techniques, procedures, material and equipment will be apparent to those in the art. It is intended that all such variations within the scope and spirit of the appended claims be embraced thereby.

We claim:

1. A system for backlighting a liquid crystal display, comprising:

a light pipe having a generally planar front surface for providing light to the liquid crystal display, having a faceted back surface wherein said back surface includes a plurality of generally planar portions parallel to said front surface and a plurality of facets formed at an angle to said front surface and located connecting said back surface parallel portions, and having at least one end surface for re-

ceiving light to be transmitted through said front surface;

light source means located adjacent each said end surface for receiving light of said light pipe for providing light to said light pipe; and

reflector means located adjacent to and generally parallel to said light pipe back surface for reflecting light back through said light pipe.

2. The system of claim 1, wherein said reflector means is generally planar and has a front surface adjacent to said light pipe back surface, said reflector means front surface including a series of grooves, the longitudinal axis of said grooves extending somewhat parallel to the longitudinal axis of said facets.

3. The system of claim 2, wherein the longitudinal axis of said grooves is somewhat askew of the longitudinal axis of said facets.

4. The system of claim 1, wherein said reflector means is generally planar and has a front surface adjacent to said light pipe back surface, said reflector means front surface being highly reflective and highly scattering.

5. The system of claims 3 or 4, further comprising:

injector means between said light source means and said light pipe for coupling light produced by said light source means to said light pipe.

6. The system of claim 5, wherein said injector means has a flat surface facing said light source means.

7. The system of claim 6, wherein said injector means flat surface is coated with an anti-reflective coating.

8. The system of claim 5, wherein said injector means includes index matching material located between and contacting said light source means and said light pipe.

9. The system of claim 5, wherein said injector means is shaped to generally conform to the surface of said light source means.

10. The system of claim 5, wherein said injector means includes a surface having a fresnel lens developed thereon.

11. The system of claim 10, wherein said fresnel lens is a cylindrical fresnel lens.

12. The system of claims 3 or 4, wherein each said end for receiving light of said light pipe has a flat surface.

13. The system of claim 12, wherein said end is coated with an anti-reflective coating.

14. The system of claim 12 wherein said end has a fresnel lens developed thereon.

15. The system of claim 14, wherein said fresnel lens is a cylindrical lens.

16. The system of claims 3 or 4, wherein each said end for receiving light of said light pipe is shaped to generally conform to the surface of said light source means.

17. The system of claims 3 or 4, wherein said light source means includes fluorescent lamps.

18. The system of claim 17, wherein said lamps are reflector lamps.

19. The system of claim 17, wherein said lamps are aperture lamps.

20. The system of claim 17, wherein said lamps are cold cathode lamps.

21. The system of claim 20, wherein said lamps are partially encompassed by insulation.

22. The system of claim 21, wherein said insulation includes a reflective surface facing said lamps.

23. The system of claim 17, wherein said lamps are hot cathode lamps.

24. The system of claims 3 or 4, wherein said light source means includes uniform dispersion fluorescent lamps.

25. The system of claim 24, wherein said light means further includes reflectors formed around said lamps to reflect light to said light pipe.

26. The system of claims 3 or 4, wherein said light pipe is formed of polymethyl methacrylate.

27. The system of claims 3 or 4, wherein the angle of said facets from said parallel portion is between 90 and 180 degrees.

28. The system of claim 27, wherein the angle is approximately 135 degrees.

29. The system of claims 3 or 4, wherein the pitch defined by the distance from successive facets is less than that required to exceed the visual threshold of a human being.

30. The system of claim 29, wherein said pitch is randomly varied.

31. The system of claim 29, wherein said pitch is uniformly varied to a maximum of approximately 1000 per inch.

32. The system of claims 3 or 4, wherein the facet height between successive parallel portions is varied between two limits.

33. The system of claim 32, wherein said facet height limits are approximately 1 and 100 microns.

34. The system of claims 3 or 4, further comprising a diffuser located adjacent to and generally parallel to said light pipe front surface.

35. The system of claim 1, further comprising a low scattering diffuser located adjacent to and generally parallel to said light pipe front surface.

36. The system of claims 3 or 4, wherein said facets are generally planar.

37. The system of claims 3 or 4, wherein said facets are portions of a generally cylindrical surface.

* * * * *

EXHIBIT 5

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EXHIBIT 6

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EXHIBIT 7

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EXHIBIT 9

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EXHIBIT 10

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EXHIBIT 11

S7-7 Directional Diffuser Lens Array for Backlit LCDs

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ABSTRACT

A directional type diffuser for backlit liquid crystal displays (LCDs) is presented. Constructed with low-cost, thin, molded plastic lens array(s) and inserted behind the LCD panel, results are: increased brightness, better uniformity, darker blacks off-axis, and better gray-scale stability with viewing angle. The approach is suitable for all transmissive displays including TN, STN, F-E, TVs, laptop PCs, avionics, and other applications.

Objectives and Background

The conventional practice for backlighting large area, liquid crystal, matrix displays (passive or active) consists of a fluorescent lamp behind a diffusing plate that projects light through the LCD.[1] The diffusing plate is typically as lambertian as practical to prevent imaging of the lamp. That is, the diffuser deliberately scatters light uniformly across angle without preference for any direction. This typical configuration serves several practical purposes. Among those practical purposes are hiding the lamp image from the viewer, facilitating the human visual system in establishing the LCD surface as the image plane, and allowing the LCD to be equally well backlit from all viewing angles for a minimum of cost, complexity and space. See Figure 1.

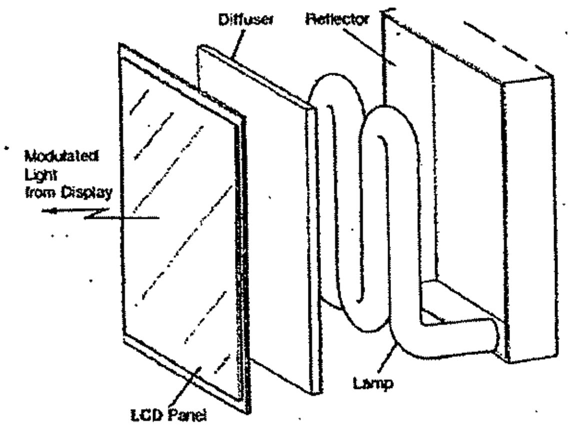

Figure 1. Exploded View of a Typical Backlit LCD

While backlighting through a lambertian diffuser provides virtually constant luminance into the rear display surface throughout all viewing angles, the transmission function of the LCD is not constant with viewing angle. This is a well known shortcoming of LCD technology. Partly due to this transmission instability with viewing angle, the practical uses for this class of display have been limited to applications with confined viewing space such as personal TVs, PC displays, video camera viewfinders, etc. Our application, flight instruments for aircraft cockpits, share common features with typical matrix LCD applications including a limited field of angular view and an undesirable, but significant, instability in the LCD transmission with viewing angle. See Figure 8.

In typical direct view applications, the limited viewing angle actually provides an opportunity to produce a more efficient backlight system. The opportunity arises from the fact that light radiated in unviewed directions is wasted and would be better directed away from those angles into useful viewing angles.[2] Obviously, this is easier said than done. We have developed a means to approach this goal by using a nonlambertian diffuser that has gain in the useful viewing angles. Naturally, as required by the conservation of energy, any gain provided by the diffuser in one direction must be offset by a loss in another direction. This is ideal for the LCD applications described here because it conserves light, directing it preferentially into useful directions while stealing it away from useless angles, thereby improving the efficiency of the backlighting system.

Not only can a directional diffuser improve efficiency, but with proper design choices, it can effectively compensate for the variability of transmission of the display with viewing angle. The directional diffuser, by definition, varies the exit luminance from its surface with viewing angle. By designing this angular variation in luminance output to be inversely proportional to the angular transmission characteristics of the panel, the panel's angular variability can be nullified. That is, when at some angle, the display is more transmissive than it is at the nominal viewing angle, that transmission error can be nullified if the luminous output from the directional diffuser at that same angle is proportionally less than it is at the nominal viewing angle. Conversely, at viewing angles where the panel is less transmissive than it is at the nominal viewing angle, that error can be nullified by a directional diffuser that produces proportionally more luminance at that angle than it does at the nominal angle.

Unfortunately, the angular transmission characteristics of an LCD panel depend largely on the gray level being displayed. It is, therefore, not generally possible to create an inverse transmission characteristic for an LCD panel with a passive directional diffuser. We can, however, approximate that end by targeting particular gray levels or families of gray levels that behave similarly with viewing angle and have a particular importance for the display.

One important gray level to target is the dark state transmission. We believe the dark state variability with viewing angle is closely related to the perceived visual quality of the display's viewing angle. This is especially true in avionics where most of the display surface is black and graphic symbols are displayed against this black background. Often, contrast is presumed to be the important figure of merit with regard to off-axis display performance. We believe, however, that high contrast in off-axis viewing angles is important to a large extent because it is typically used to reduce the dark state, off-axis luminance. That is, a key perceptual factor in accessing display quality across viewing angle is the darkness of the background. That this aspect of display quality is independent of contrast is made clear with the directional diffuser which is incapable of affecting contrast at any viewing angle, but exhibits markedly improved off-axis display quality, nonetheless, in proportions normally attributed to high contrast.

In many applications, including ours, the angular variability of lower gray level transmissions behave similarly to the dark-state transmission. Thus, tailoring the directional diffuser to reduce dark state variability has the added benefit of reducing the variability of lower gray levels as well. Maintaining the luminance stability of these lower gray levels with viewing angle is important to image quality because it is these low gray levels that are recruited to make colors such as brown, gold, and gray, for example. These "colors" are dim versions of orange, yellow and white respectively and depend just as heavily on their relative luminance to the surround

for their perception as they do on their color coordinates. Therefore, to effectively render these colors on the display over the entire angular field of view, it is important that the luminance of the low gray levels be stable with viewing angle.

Results

To construct our original directional diffuser prototype we used an off-the-shelf, 142 lenses per inch (5.6 lenses per mm), molded plastic, cylindrical lens array placed between the LCD panel and a lambertian diffuser. Figure 2 shows our modified diffusing system in cross section. An examination of first principles led us to question how this construction could produce the gains it did since refraction of the light through the lens array from a lambertian source should not produce gain. The subsequent investigation showed that there is a concert of several optical effects combining to produce gain, including diffuse reflections, lens refraction, and total internal reflections.[5] Figure 3 shows the luminance versus angle response from the single cylindrical lens directional diffuser case compared to the angular response from the lambertian source diffuser.

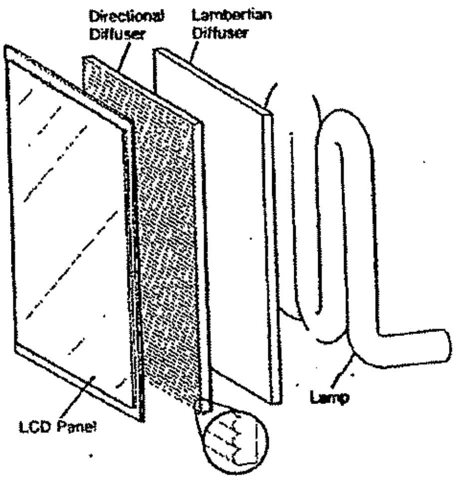

Figure 2. LCD with Directional Diffuser

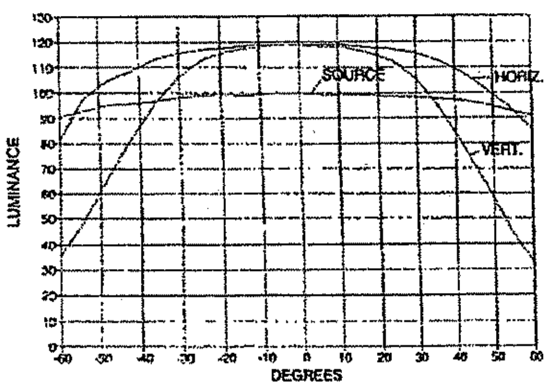

Figure 3. Single Cylindrical Lens Array Angular Emissions

Theory of Operation

As illustrated in Figure 4, light rays from the lambertian diffuser source impinge on the lens array from all angles. Rays with propagation vectors that are substantially perpendicular to the tangent of the lens curvature pass through the lens array suffering Fresnel reflections at the entrance and exit surfaces of the lens array as well as some refraction. Note that these rays are not necessarily normal to the plane of the array but rather essentially normal to the curvature of the lens which spans 180 degrees. However, much of the intensity of rays substantially off the normal to the array will be reflected back toward the lambertian diffuser source through Fresnel reflections at the entrance surface of the array and at the lens curvature surface. These Fresnel reflections are not, in themselves, losses since the reflected light is directed back toward the lambertian diffuser. There, it is diffusely reflected again, and together with currently generated light from the lamp source, impinges on the lens a second time. However, reflections at the lambertian diffuser source are, in general, lossy as a result of some absorption in the reflections and absorption along the added optical path. We have found that these losses can be minimized by design choices, especially material selections, at great benefit to the efficiency of the lighting system.

Rays entering at oblique angles relative to the curvature of the lens, that are greater than the critical angle, undergo total internal reflection. These rays are reflected several times around the lens periphery and exit the rear of the lens array aimed back at the lambertian diffuser. As described before, these reflected rays then undergo a diffuse reflection from the lambertian diffuser source, are combined with light generated by the lamp source and are presented a second time to the rear of the lens array with another chance to pass through the LCD. Since light entering at these oblique angles is selectively rejected and realigned until accepted by the lens array, the lambertian diffuser and lens array combination preferentially transmits light in directions substantially normal to the plane of the array in the axis of the lenslets with only a modest effect on the opposing axis. See Figure 3 where vertical refers to the lenslet axis.

Alternate Configurations

This theory of operation of the prototype directional diffuser configuration serves to illustrate the basic principles involved, but does not necessarily imply the optimal arrangement or even the preferred construction of an optical element used as a directional diffuser. For example, another useful configuration results from flipping the lens array over such that the curved lens surface faces the diffuser. In this case, light exiting the diffuser impinges on the convex curvature of the lens array first. This results in preferentially directing light away from the normal to the plane of the lens array and into oblique angles. In other words, this configuration throws light into off-axis angles at the expense of on-axis luminance and can aid in cases where display brightness suffers off-axis. This configuration has an on-axis gain slightly less than one.

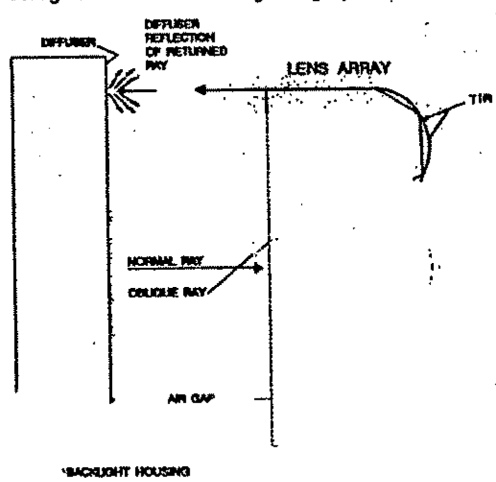

Figure 4. Sample Ray Paths Through Directional Diffuser

Combining multiple lens arrays, stacked one in front of the other relative to the light path, either with the lens' major axis aligned or rotated with respect to each other also has useful effects. Figure 5 illustrates a dual lens array configuration. As you can intuitively imagine, the pitch of the lens array is independent of the transmission versus viewing angle gain profile which depends only on the lens shape. This allowed us to combine the effects of two lens arrays with their major axis aligned without moire pattern effects by using different pitches on each array. This particular arrangement provides sharper roll off of the luminance with vertical viewing angles without much change to the on-axis gain. See Figure 6.

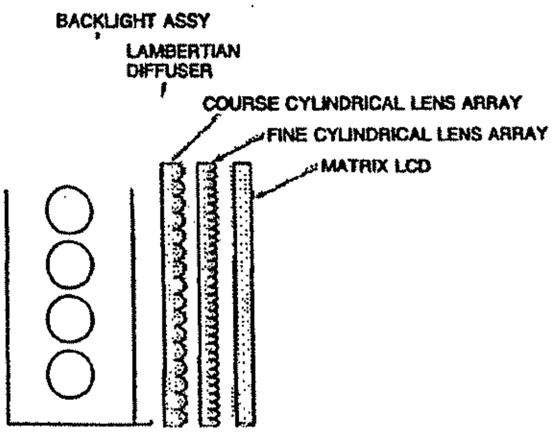

Figure 5. Dual Lens Array Configuration

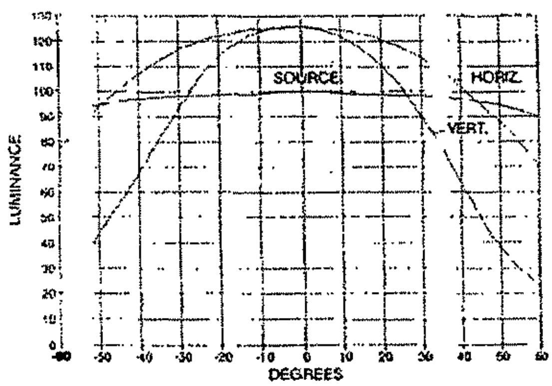

Figure 6. Dual Lens Arrays Optical Characteristic

We have been especially interested in the advantages of such tandem, rotated (90 degrees), lens arrays combined with a diffusing reflector box rather than a diffuser plate as the diffuse source. The advantages are fewer losses and better uniformity due to the larger reflector enclosure serving as an integrating cavity. While the gain profile of the lens array is independent of pitch, the diffusing power of the lenses in this configuration is very much dependent on the lens pitch.

Computer Analysis

Most commercially available optical ray trace programs are designed for imaging optics with lenses placed along an optical axis. These programs are not well suited to analyzing the directional diffuser primarily because of the lateral extension of the diffusing source. Much of our understanding, analysis, and synthesis results of the directional diffuser came about through a customized, ray trace computer program developed for us by Fresnel Technology Inc.[3] Ray tracing of multiple rays with a computer has verified the gains and angular distribution of emitted light from directional diffuser configurations.

This ray trace program was used to examine a number of candidate lens arrays with varying lens shapes. It was found that a triangular array with a 90 degree apex angle provided the most gain on-axis. While the angular distribution was too narrow for our application (see Figure 7), it may be well suited for other applications. The next higher gain was found to be obtained with the cylindrical lens. Asymmetrically shaped or truncated lenses yielded symmetrical angular distributions about the normal axis, but had reduced gain over non-truncated shapes. We also found that while an air gap (or other form of a refractive index discontinuity) must be present between the lambertian diffuser and lens array, the surfaces may contact randomly with no noticeable effect.

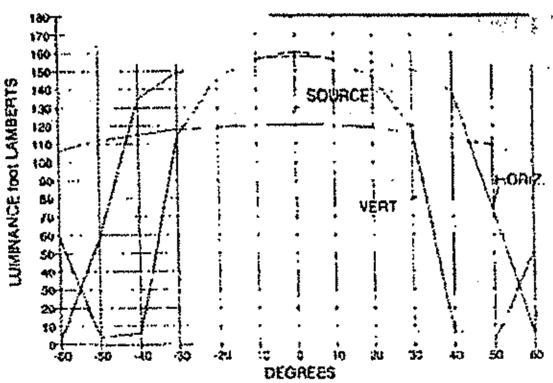

Figure 7. Triangular Lens Array Optical Characteristic

Moire Pattern Treatment

From the beginning we were certain that moire patterns would be a major obstacle to a successful realization of a practical directional diffuser married with an LCD panel. However, we were pleased to find that moire pattern, caused by the beating between the lens pitch and the display dot pitch was much easier to deal with than we first imagined. By using a lens pitch that was higher than, and between integer multiples of, the display pitch we were able to counteract most of the moire.[4] A slight rotation of the lens array's major axis relative to the cardinal axes of the display panel served to frustrate the pattern and thereby eliminate any remaining moire for all practical purposes. Naturally, alphanumeric displays and displays with small, disassociated symbols are least susceptible to moire effects; but we were able to eliminate noticeable moire from all symbols including full-field presentations of solids and patterns.

Combined LCD and Directional Diffuser Results

Figure 8 shows the gray level luminance versus vertical viewing angle for our normally black LCD with a conventional, lambertian diffuser, Figure 9 shows this same panel performance when backlit with the dual-aligned lens arrays profiled in Figure 5. Notice how stable (flat) low level grays are near the nominal viewing angle of 15 degrees up. Also, notice that the black level (lowest gray) remains much darker across viewing angle than when backlit with a conventional diffuser.

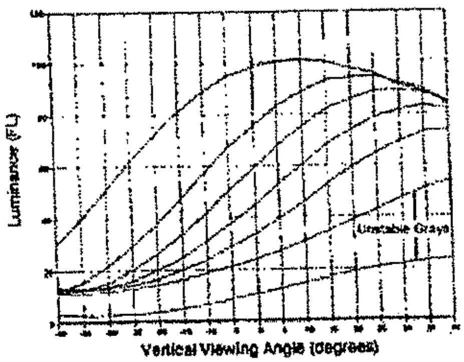

Figure 8. Gray Scale Luminance with Viewing Angle and Conventional Diffuser

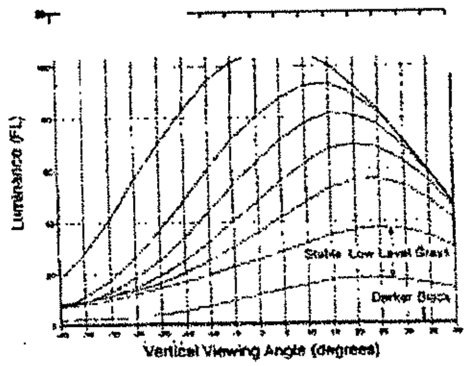

Figure 9. Gray Scale LCD Luminance with Dual Lens Directional Diffuser

Impact

We believe the molded lens array, directional diffuser we have developed and presented here with its approximate 15 percent efficiency improvement to the on-axis output from the backlight system can benefit most LCD applications. The technique is applicable to a wide body of transmissive display technologies including TN, STN, and ferro-electric LCDs. Of particular importance to many applications is that the directional diffuser increases on-axis luminance of the backlight system that can be used in any number of ways including lower lamp power, longer lamp life and/or a brighter display. In portable applications, these benefits can translate directly into longer battery life and/or smaller size and/or lower weight. We believe that for most consumer applications, the efficiency benefit of the directional diffuser alone can justify the relatively low cost of this simple optical element. The benefits of improving display stability with viewing angle and potentially improved display uniformity across the panel, for the most part, come for free.

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References

1. Whitehead et.al., 'Light Distribution Methods for the Backlighting LCDs, TIR Systems, LTD., SID 1992, 419-422.

2. Jacobson et. al., "Flat Panel Fluorescent-Lamp backlights with Reduced Illumination Angle: Backlighting Optics at the Thermodynamic Limit," NiOptics Corp., SID 1992, 423-424.

3. Private Report from Fresnel Technologies, Fort Worth, Texas, USA.

4. H. Noda et.al., "High Definition Liquid Crystal Projection TV," Japan Display 1989, 256-259.

EXHIBIT 12

THIS EXHIBIT HAS BEEN REDACTED IN ITS ENTIRETY